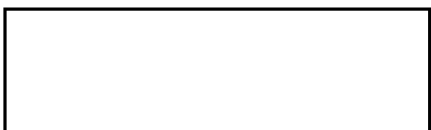


Handwritten signatures and initials in the top right corner, including "SWC" and "JWC".

STATINTL


4 January 1960

STATINTL



Dear Bob:

Transmitted herewith are two (2) copies of the final report on our Task Order No. 1.

We have forwarded three (3) copies of this report to the Contracting Officer and we have asked him to forward copies to the project engineer, who we assume is still  for Task Order No. 1.

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STATINTL

Very truly yours,



Contract Administrator

HRE/pe

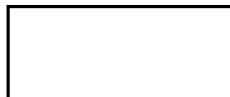
Declass Review by NIMA/DOD

FINAL REPORT ON FEASIBILITY PROGRAM

FOR A

UNIVERSAL PHOTOGRAPHIC RECTIFIER PRINTER

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Final Report on Feasibility Program for a
Universal Photographic Rectifier Printer

1. Introduction

A. General

This document is submitted as the final report completing all work contemplated by the contract for development of an electronic rectifier. This program has included the engineering design and fabrication of an engineering model of the device. The rectifier operation was satisfactorily demonstrated to representatives of the Contracting Officer on 5 October 1959.

The problem was to correct for tilt transformation in panoramic and high oblique photography by an electro-optical technique. The intent of this technique was to retain more image detail than by other means and to produce an equipment with a wide range of possible image geometry transformations.

The equipment produced on this program has fulfilled the requirements of the contract as well as showing future possible applications and the operating characteristics of these equipments.

The results of the study and performance tests are reported herein together with conclusions and recommendations for future equipment.

B. Statement of Requirements

The specifications set for the engineering model were:

- a. Negative Panoramic Camera Film-70 mm wide.
- b. Print 8 1/2 inches film or print paper
- c. Enlargement. Four times (4X) at the nadir point
- d. Maximum oblique rectification. ± 65 degrees from nadir point
- e. Maximum resolution. 30 lines per millimeter with respect to negative.
- f. Scanning time Minimum possible

The intent of this program was to study feasibility and make a working model of a universal rectifier which was not limited (in principle) by any geometrical transformation useful to a photogrammetrist. To accomplish this result numerical control with pre-programmed punched tape (containing all variables) was desired.

C. Description of System

The functional block diagram of the system is shown in Figure 1.1. The negative is illuminated by a point source of light from a flying spot scanner. Light transmitted through the negative is converted to a voltage (or video signal), by the P. M. T. The image data displayed on a printing CRT is projected upon photographic printing material. By simultaneously scanning the reading and printing CRT the negative is illuminated and the print is exposed.

Three types of scans are used. Line segments are electronically scanned by the cathode ray tubes. The projection lenses are translated across the negative (and print) to develop the line segment scans into a strip scan. After each strip is scanned, the negative (and print) is indexed to scan the adjacent and contiguous strip.

Electronic sweeps are generated by a sweep generator. The printing line scan is made with constant light spot amplitude and velocity. The printing lens moves with constant velocity and amplitude throughout the rectification to ensure an even exposure. The reading line scans are varied in length and orientation to provide the desired transformation. This is done in the sweep attenuators which respond to numerical commands from the program tape. Similarly the reading lens position is determined by the instantaneous printing lens position and punched tape data. The print index interval is fixed but the negative is positioned from program data and a digital servo.

D. Summary of Results

The study portion of this program determined the most desirable techniques and components for instrumenting the equipment. The engineering model was produced with off-the-shelf components to demonstrate the feasibility of the performance requirements. Figure 1.2 is a photograph of the major components.

To demonstrate feasibility a panoramic photograph with a superimposed rectilinear grid (with respect to ground datum plane) was rectified. This photograph is shown after rectification and enlargement in Figure 1.3. A non rectified enlargement programmed in the machine printed the photograph shown in Figure 1.4.

To demonstrate the resolution preserved through the system a standard Air Force resolution target was enlarged in the Rectifier-Printer. After 5X additional enlargement (a total of 20X) the 30 line per millimeter target was still resolved. See Figure 1.5.

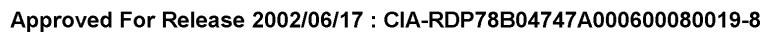
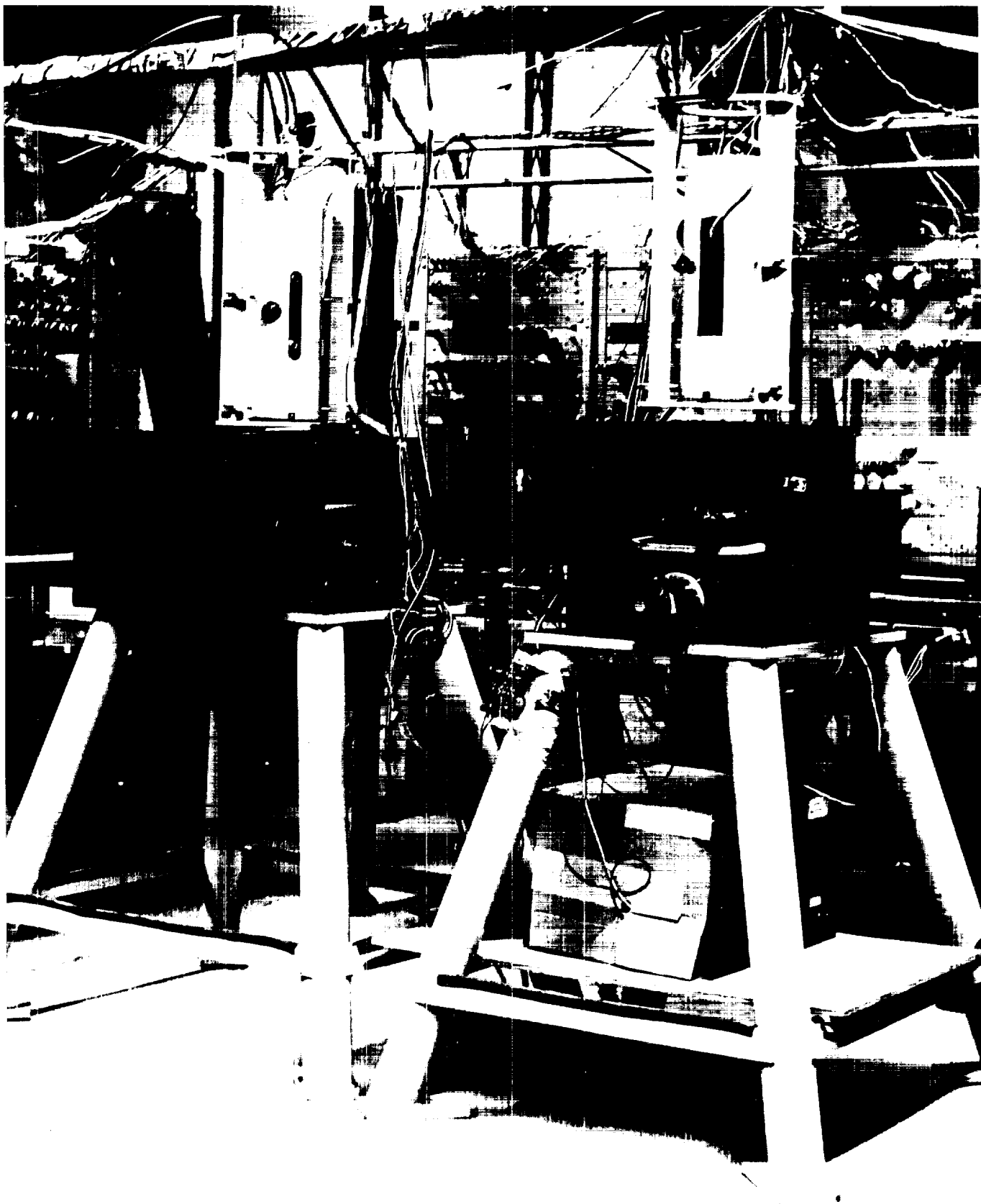
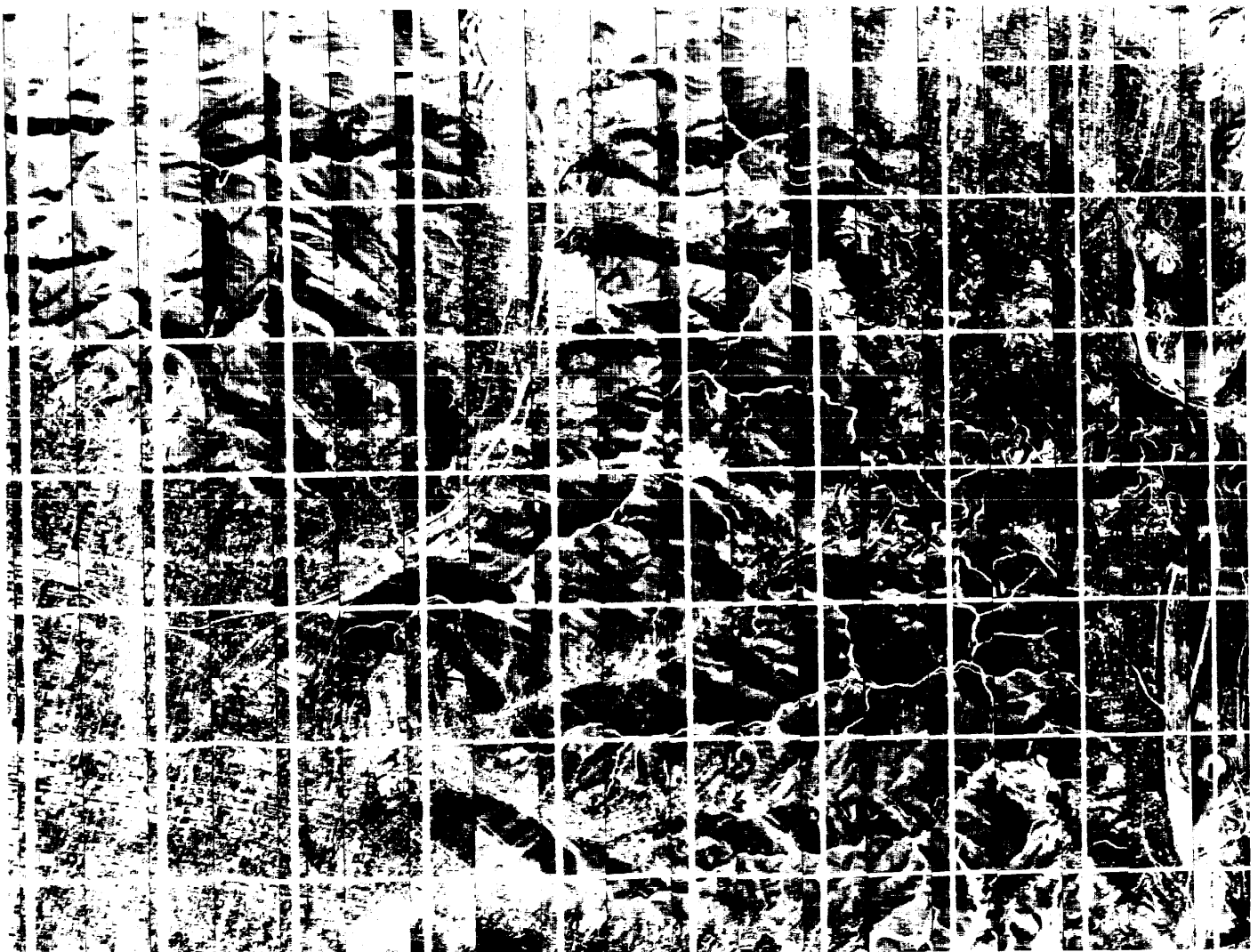


Figure 1-1. Functional Block Diagram.



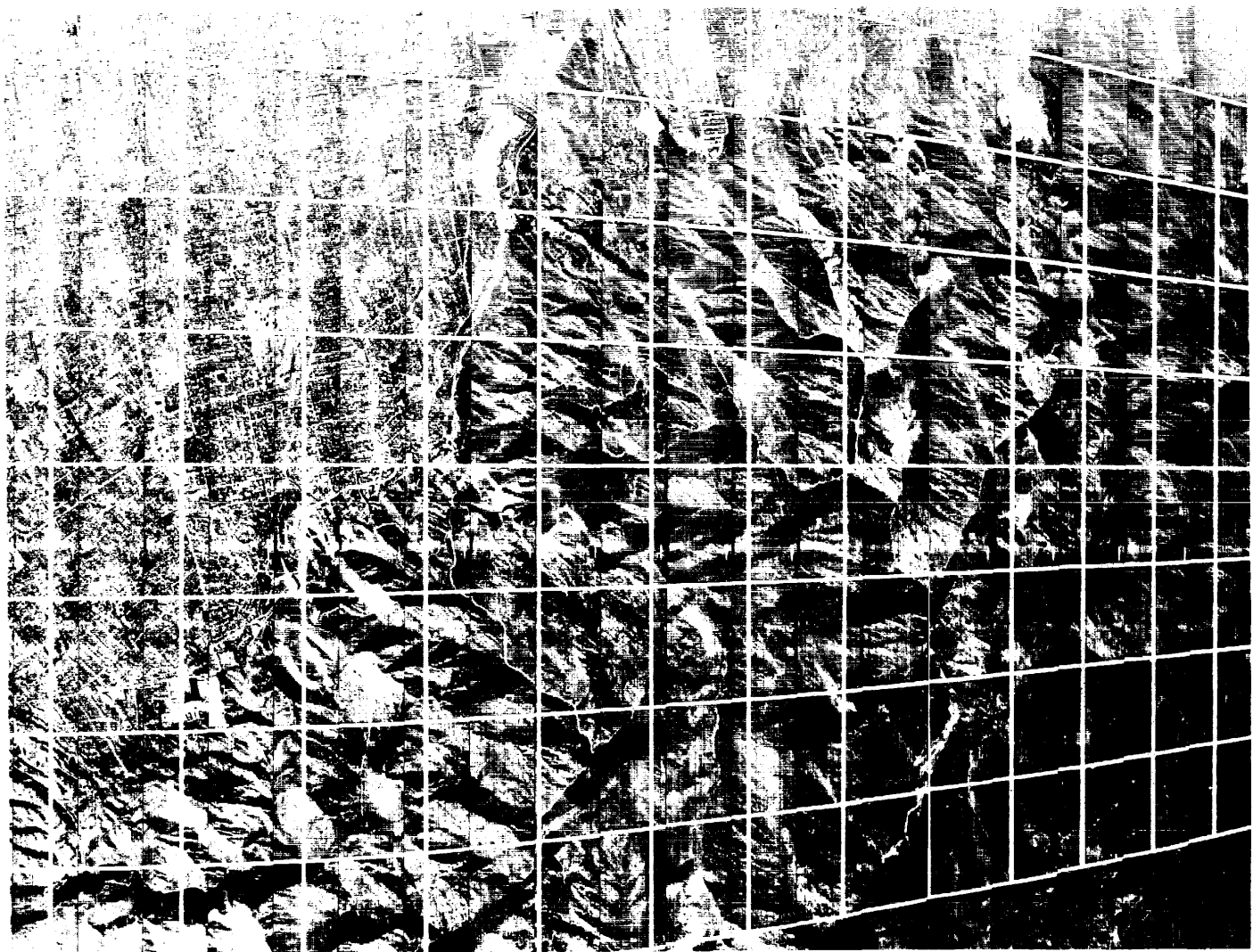
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Figure 1-3. Panoramic - Rectified and Enlarged.

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Figure 1-4. Panoramic - Unrectified and Enlarged.



Figure 1-5. Resolution Chart.

II. Performance Tests

A. Electro Optical Sub-System

The electro optical sub system consists of the projection system shown on the left side of the functional diagram in Figure 1.1. This system was tested for factors affecting photographic quality as follows:

Test 1 - Reading Resolution

Reading resolution was determined by measuring the rise time of the video signal by scanning across a sharp edge in the reading image plane using a 1/8 inch line scan at the rate of 1 millisecond per scan. The rise time created by an instantaneous contrast variation was 4 microseconds. This shows a total of $0.001/0.000004$ second or 250 very high contrast spots (or T. V. lines) are well resolved, in a 1/8 inch line scan.

The outcome of this test shows the resolution in one direction is 2,000 T. V. lines per inch or 40 optical lines per millimeter. Resolution in the other direction was proven to be at least as good by a subsequent test (See Test 3).

The principal factor limiting resolution is the flying spot diameter. This test showed that the effective spot diameter was approximately 0.002 inch at the CRT (including such additional effects as lens aberrations and vibration).

The resolution was unaffected when different projection lenses were used. Reading lenses tested were the f/4.5 and the f/2. STATINTL

NOTE: It must be remembered that 40 optical lines per millimeter (or equivalent 0.005 inch spot diameter) were highly resolved. This test method is recommended in "Cathode Ray Tube Recording Symposium" January 13-14, 1959.

Test 2 - Printing Resolution

To test printing resolution a dot pattern was generated electronically and displayed on the printing kinescope. The proximity of dots in the pattern required was such that (after printing) a resolution of 20 optical lines per millimeter was necessary in the printer if they were to be distinguished.

When the dot pattern was exposed and developed the dots were well resolved. In subsequent prints, this pattern was superimposed (overprinted) 40 times in exposure. It was still possible to resolve 20 optical lines per millimeter with good contrast. This test showed the resolving capability of the printing system and provided proof of positioning accuracy of the CRT spot as well as the quality of the power supplies and sweep system. (NOTE: A printing resolution of 20 lines per millimeter corresponds to 80 lines per millimeter at the negative because of the 4X enlargement).

Test 3 - System Resolution

The system resolution was tested by an enlargement of a standard Air Force resolution chart. See Figure 1.5. This figure showed that approximately 30 optical lines per millimeter were resolved throughout the system.

The system resolution was limited only by the two cathode ray tubes. Essentially no degradation was allowed by any other elements of the electronic system. Optical degradation due to the lead screws was so small that it could not be detected in the final system.

Test 4 - Dynamic Range of Exposure

Although the printing kinescope permits a dynamic range of approximately 100 to 1, the overall dynamic range of the system is limited to approximately 30:1 because of reading system limitations. This limitation is a low signal to noise ratio at the photomultiplier. To improve this ratio will require (1) more light from the flying spot scanner, (2) a better projection lens (larger relative aperture), or (3) less noise in the photomultiplier.

Little improvement can be expected from cathode ray tubes since the desire for smaller spot size is not consistent with more illumination. A major increase in light output is required with a small spot. Reduced spot halation will also improve the system signal to noise ratio.

Test 5 - Print Material

No extended tests were made with different print materials. The printer light intensity was adequate to print on ASA 80 film. The results achieved on film indicate that the speed of most available print papers would be marginal.

Test 6 - Image Enhancement

The method of dodging consists of an automatic gain control system to control the exposure with respect to the 1/8 inch by 1/8 inch strip previous to the image element being exposed. This type of control provides good average exposure, however, it is not satisfactory for a final system because the exposure between adjacent strips can become mismatched by large ground details. Using an auxiliary lighting system to illuminate the context of the spot would provide the same overall dodging but eliminate mismatch in strip densities.

B. Scanning Mechanisms

Test 7 - Electronic Scanning

The accuracy of location of the flying spot scanning system was discussed in Test 2. The sweep attenuators used for control have a maximum possible error of 2 parts in 1,000. That is, the maximum line scan segment on the negative (1/8 inch) is in error by less than 0.001 inch from this source. The principal error experienced in positioning the flying spot arises from calibration difficulty. The probable error in spot positioning (and edgematching detail) is 2 or 3 image elements (approximately 0.001 inch total). This has been proved in test. The present method of calibrating sweep amplitude can be improved in future models by using a calibrating reticule with accessible calibration controls.

Test 8 - Indexing Accuracy

The Printer indexing mechanism accuracy is 0.001 inch.

The Reader negative can be positioned to less than 0.001 inch. The digital servo depends on lead screw and programming accuracy and each contributes no more than 0.0004 inch error in positioning.

Test 9 - Lens Positioning Accuracy

The instantaneous lens position error is less than 0.001 inch when the mechanism is synchronised. The control and programming system contribute 0.00025 inch error in the lens position. The remainder of the error is made up in gear train and lead screw tolerances.

The lens carriage servo-mechanism has an arbitrary delay in synchronizing with the system. This is created because the carriage cannot be permitted to stop or reverse during the starting servo transient. A forward backward counter will cure this limitation in any future models.

C. Control System

The numerical control system employed is unique. The accuracy that is obtained from numerical control has been reported in tests 7, 8 and 9. The only additional program error is caused by using linear line scans (or a constant velocity flying spot) in the Reader. Since the scale of the negative is continuously variable a non-linear scan is desired. However, with small scans the placement error from this source is negligible (.0003 inch maximum).

III. Operating Considerations

A. Set Up

Before the negative can be rectified it is necessary to determine the line of principal points and the nadir point. Additional transformations can be added (such as V/H shearing, etc.). The mechanism in the engineering model now limits rectification to those transformations resulting in straight lines of constant scale.

The mathematical analysis of the transformation is required to prepare the tape program. Most transformations are fairly simple analytically. The variables to be programmed can be determined from an arbitrary printing scan pattern.

After completion of the calibration procedure which requires CRT line scans to be adjusted with test reticules, and the exposure set, the negative is aligned in the Reader and the punched tape is loaded in the tape reader.

B. Operation

The entire operation is automatic. Under present specifications a Tracker Film negative can be rectified in forty minutes.

IV. Conclusions and Recommendations

A. Scanning

The method of scanning is a good selection for this application which requires accuracy and resolution. A maximum program error of 0.0003 inch

(placement error) is caused by constant velocity spot scans in a direction of varying scale. This permits the accuracy over large portions of the format to be determined by mechanical scans. Accuracy of electronic scans is less critical because the amplitudes are small and any error is not cumulative over the format.

B. Resolution, Exposure, and Speed of Operation

Future improvement in resolution is limited by the illumination from the flying spot, the projection lens, and spot size. Since contrast is limited by the illumination from the reading light spot, reduction in spot size should be accompanied by increased phosphor efficiency or greater permissible phosphor loading. This is required to prevent loss of total light output. Reduced noise in the photomultiplier is another alternative.

Further optical reduction of the spot will also improve resolution, however, this too will reduce the light to the photomultiplier. Lens variations to improve spot size and illumination are:

- 1) Large relative aperture
- 2) Less light absorption

Higher resolution will require the scanning time to be increased as the square of the improvement ratio (measured in terms of resolution).

C. Accuracy

The primary limitations to positioning accuracy are precision of transducer measurement and sweep calibration. The present position transducers depend upon lead screw precision for accuracy. The use of optical gratings can remove this source of inaccuracy. The line scan amplitude error is largely caused by difficulty in calibration. The use of a calibrating reticule and more accessible controls are desirable improvements.

D. Control

The control system can produce placement errors as great as 0.0004 inch. Improvement would require choice of smaller digital increments. The principle disadvantage of the present control system is the "lock in" time. The delay in lens positioning can cause shearing of the image at the beginning of scans. This is not a basic fault but is caused by an artifice employed to eliminate the need for bidirectional counters.

Tests on the lens controller show that non-linear scans can be programmed very accurately. This type of scan will be required to rectify photographs that do not contain straight lines of constant scale.

The numerical program has been determined for a panoramic rectification. It is estimated that with existing program data less than four hours should be required to program a new transformation. More of the computation could be included in the rectifier, however, this would be at increased cost and reduced versatility.

E. Future Equipment

The feasibility of the rectifying technique has been shown. Future equipments would require Printer and Reader consoles and a Control Rack. It is desirable to produce this equipment with provision for increased film size, higher resolution, and greater operating speed.